NUCLEAR SPIN CATALYSIS IN LIVING NATURE: PREMISES AND PROMISES

Koltover V.K.

Institute of Problems of Chemical Physics, RAS, Chernogolovka, Moscow Region, Russia
E-mail: koltover@icp.ac.ru

Cells are composed from atoms of chemical elements, many of which have magnetic and nonmagnetic stable isotopes. In chemical physics, magnetic isotope effects (MIEs) have long been known. Not long ago, MIEs have been discovered in the experiments with living cells enriched with the magnetic or nonmagnetic isotopes of magnesium. Moreover, MIEs have been revealed in the experiments with one of the important molecular motors of cell bioenergetics, myosin, isolated from smooth muscle (Koltover et al., 2016). The rate of the enzymatic ATP hydrolysis has occurred 2.0–2.5 times higher with magnetic ^{25}Mg than that with nonmagnetic ^{24}Mg or ^{26}Mg. Besides, MIE has been revealed in the experiments with zinc isotopes. While Zn^{2+} performs the cofactor function less efficiently than Mg^{2+} it has been found that the rate of the ATP hydrolysis driven by myosin is 40-50 percent higher with magnetic ^{67}Zn as compared to nonmagnetic ^{64}Zn or ^{68}Zn. Furthermore, the beneficial MIE of ^{25}Mg has been discovered in the ATP hydrolysis catalyzed by mitochondrial H^+-ATPase (MF_0F_1 complex) isolated from yeast cells and reconstituted into the proteoliposome membrane. The initial rate of the ATP hydrolysis with ^{25}Mg has turned out to be about 20 percent higher as compared to the rate with the nonmagnetic magnesium isotope. On its own, factual evidence of MIE unambiguously indicates that there is a spin-selective rate-limiting step, a "bottle-neck", in the process under investigation that is accelerated by the nuclear spin of ^{25}Mg and ^{67}Zn. The most plausible biophysical mechanism of the catalytic effect of the nuclear spin can be suggested as follows. The energy released during ATP hydrolysis (~0.54 eV) is not large enough for the electron-conformational transition of the macromolecule into a singlet exited state. This energy is sufficient to produce a low-level triplet state (S = 1) but the transition from the ground state (S = 0) to the triplet state (S = 1) is forbidden by the law of conservation of spin. The magnetic isotope's nuclear spin eliminates the spin ban providing the required conformation transition and, thereby, accelerates the chemo-mechanical cycle of the enzyme. The alternative explanation of the MIEs in the enzymatic hydrolysis of ATP suggests a possible role of the virtual radical-ion pair. Another alternative considers the increase in the conversion rate of the ortho/para isomers of water molecules by the nuclear spin of ^{25}Mg and ^{67}Zn (Koltover, 2017). Although detailed mechanisms of ability of the biocatalysts to perceive the nuclear magnetism require further investigations, there are the grounds to believe that this new field, nuclear spin catalysis, highlight promising venues for future research with possible application of the stable magnetic isotopes in engineering and medical physics.

References

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